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# Effects of carbaryl, trichlorfon, and DDT on collapsing Douglas-fir tussock moth populations in Oregon

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Carbaryl, trichlorfon, and DDT were tested on collapsing field populations of Douglas-fir tussock moth in eastern Oregon. DDT applied at the rate of 0.75 lb a.i./1.0 gal/acre (340.20 g a.i./3.78 1/0.404 ha) was the most effective treatment in reducing tussock moth (DFTM) populations and preserving tree foliage. Trichlorfon applied at the rate of 1.0 lb a.i./5.3 pt/acre (453.59 g a.i./2.51 1/0.404 ha) was not significantly different from DDT in preserving foliage, but was less effective in reducing DFTM populations. Carbaryl applied at the rate of 1.0 lb a.i./0.25 gal/acre (453.59 g a.i./0.95 1/0.404 ha) was not as effective as DDT in preserving foliage and reducing DFTM populations. Differences in volumes of the insecticides applied, droplet sizes, and spray distribution affected their coverage of the study plots and the test results. Virus played a major but unmeasured role in reducing tussock moth populations. Data also indicated that virus-infected larvae survived the insecticide treatments better than healthy larvae.

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*Retrieval Terms:* Tussock moth; Douglas-fir tussock moth, *Orgyia pseudotsugata;* insecticides; carbaryl; trichlorfon; DDT; population collapse.

Among alternatives to DDT that were considered in 1973 for control of the Douglas-fir tussock moth (DFTM) (*Orgyia pseudotsugata* [McDunnough] ), carbaryl (Sevin-4-oil), and trichlorfon (Dylox 1.5) showed the most promise.[1] That year, these two insecticides were field tested against high DFTM populations in the Blue Mountains of Washington and Oregon. Some control measured in number of larvae killed and quantity of foliage protected was achieved. Both chemicals, however, fell short of achieving the desired protection to forest stands.[1] Among the reasons cited for the high variability in the field performance of carbaryl and trichlorfon were: poor application strategy, inadequate coverage, and low spray deposits.[2] The fact that trichlorfon was sprayed in diluted form may have been another reason for its ineffective performance.

In 1974, we tested carbaryl and trichlorfon in undiluted formulations, with DDT serving as the "field standard."[3] Results of that study are reported here.

## MATERIALS AND METHODS

A survey of DFTM egg masses in fall 1973 indicated that insect populations would be high enough in 1974 to inflict severe damage in Idaho, and on the Blue Mountain ranges of eastern Washington and Oregon. If conditions warranted, DFTM-infested forests on all State and private lands and on the major portion of Federal lands were to be treated with DDT. In addition, a portion of the Federal lands was to be set aside for testing microbial and chemical insecticides. DFTM population densities and incidence of virus in these populations would determine which areas would be selected for testing.

So that DFTM mortality caused by the insecticides could be distinguished from that caused by a nuclear polyhedrosis virus, a threshold level of polyhedrosis in DFTM populations had to be established. We set the criteria from 0 to 5 percent of young DFTM larvae 14 days after hatching.[4]

### Treatments

The field test was to compare the effects of DDT, carbaryl, and trichlorfon formulations applied 4 days after 70 percent of the egg masses had started to hatch in terms of (a) immediate suppression of DFTM populations, and (b) preservation of the new (current year's) foliage.

Although the three insecticides are similar in toxicity to the DFTM,[5] they were applied at different dosages and volumes. DDT was diluted in diesel fuel and applied at the rate of 0.75 lb a.i./1.0 gal/acre (340.208 a.i./3.78 1/0.404 ha). Carbaryl was applied undiluted at the rate of 1.0 lb a.i./0.25 gal/acre (453.59 g a.i./0.95 1/0.404 ha) and trichlorfon was applied undiluted at the rate of 1.0 lb a.i./5.3 pt/acre (453.59 g a.i./2.51 1/0.404 ha). The rate for DDT was based on the dosage considered to be effective in the past in controlling the insect.[6] The dosage rates of carbaryl and trichlorfon were based on the manufacturers' recommendations.

The insecticides were applied by a Bell 206 (Jet Ranger) helicopter equipped with a 150 gal (568 l) underslung belly tank, an electric pump, a 50-foot (15.24-m) boom, and Tee Jet nozzles with No. 8002 nozzle tips. In all tests, boom pressure was 60 psi (42,184.20 kg/m$^2$) and nozzles oriented 45° forward and down for maximum breakup. Number of nozzles used was determined by the gallonage being applied for each chemical and varied from 15 for carbaryl to 60 for DDT. The helicopter applied the material in 100-foot (30.50-m) swaths flying at 60 mph (96.6 km/h), 50 feet (15.24 m) above tree tops.

The four treatments (three insecticides and one check) were replicated three times on 12 study plots. Each plot was 60 to 80 acres (16 to 32 ha). Twelve study plots were arranged into three groups of four plots each, corresponding to a randomized block design.

### Study Sites

Two DFTM-infested areas, one west of Troy, Oregon, and the other northwest of Halfway, Oregon, were sites for the insecticide field tests. A survey of DFTM egg masses had indicated a highly variable viral incidence among insect populations in these areas. To obtain current information on the incidence of virus, over-wintering egg masses were collected again in these areas in April 1974. We found that an average of 12 percent of the DFTM larvae from the Troy outbreak and 40 percent from the Halfway outbreak had acquired nuclear polyhedrosis from contaminated egg masses.[7] These data indicated that the DFTM populations were on the verge of collapse in the two areas.

We would have preferred to cancel or move the tests to an area that had a more suitable population, i.e., one with a high moth population and low viral incidence. The field tests, however, were one of the conditions imposed on the U.S. Forest Service by the U.S. Environmental Protection Agency when it granted permission to use DDT in the control program. The Troy area was ruled out because logging had been started on more than half the area. Thus, the tests were conducted on the Halfway area, even though we realized that population characteristics were not the most desirable and would substantially influence our data.

DFTM populations were low in density and spotty in occurrence throughout the study area near Halfway, Oregon. The experimental design required 12 study plots, each 40 to 80 acres (16 to 32 ha). We could identify only 17 possible study plots on the basis of counts of new egg masses and some degree of isolation from nearby potential plots. We selected the 12 that had the most new DFTM egg masses.

### Population Sampling

After the study plot boundaries were marked by colored ribbons,[8] we selected 40 trees and divided them into four clusters of 10 trees each for DFTM population sampling and foliage assessment. An extension pole pruner was used to cut four 15- to 18-inch twigs from the midcrown of the study trees for the prespray sample and eight twigs for the postspray sample. Foliated length and width of each sample twig at the widest point was measured. Total number of current year's shoots and number of shoots showing signs of defoliation were counted on each sample twig.

From 26 to 52 egg masses were collected from each plot to rear larvae and check for viruses (*table 1*). Treatments were begun 4 days after 70 percent of the DFTM egg masses started to hatch. DFTM larval populations on each tree were sampled 24 hours before treatment and at 4 and 14 days after treatment, using a modification of Mason's[9] sampling procedure. All DFTM larvae were counted, placed in

vials, and taken to Corvallis, Oregon, to determine extent of polyhedrosis.[10]

### Spray Deposit

Spray deposit was sampled from aluminum plates and white Kromekote cards placed in openings in the forest canopy nearest each sample tree. The plates and cards were positioned 1 to 2 hours before treatment and were collected within 2 hours after treatment. Amount of spray deposit was determined by fluorometric analysis.[11] Amount of deposit on the plates was converted to gal/acre. Droplet VMD's[12] and densities were determined from the spray collected on the white cards. Spray atomization was assessed by the drop-size spectra method.[13]

## RESULTS

Results were heavily influenced by the prevalence of nuclear polyhedrosis in DFTM populations on the study site. High incidence of the virus disease in the hatching larvae—previously estimated to be 40 percent—was verified in the egg masses collected on each plot and by larval collections made during each sampling period (*tables 1, 2*). Data indicated high mortality among hatching larvae. As a result, prespray population densities were low and varied from tree cluster to tree cluster and from plot to plot. High variability in DFTM populations due to virus could have been compensated for by a larger experiment whereas the statistical power of an experiment with three treatments and control and only three replications is poor. This fact must be kept in mind when interpreting the results of this study.

Even though initial populations were low and variable, treatments apparently had some degree of efficacy (*table 1*). Effectiveness was evaluated by comparing foliage preservation and population suppression among the treatments. We measured foliage preservation by computing the percent of shoots (new foliage) affected by DFTM feeding. The data showed the DDT and trichlorfon significantly saved

Table 1—*Population reduction of Douglas-fir tussock moth populations, before and after spraying, by incidence of virus, densities, and damage to shoots at Halfway, Oregon, 1974*

| Treatment and plot | Population Reduction | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Incidence of virus | | DFTM/1000 sq. in. foliage | | | DFTM/100 shoots | | | Shoots affected | | |
| | Egg mass sampled | Larvae with virus at 14 days | Prespray | Postspray | | Prespray | Postspray | | Prespray | Postspray | |
| | | | | 4 days | 14 days | | 4 days | 14 days | | 4 days | 14 days |
| Check: | | *Percent* | | | | *Density* | | | | *Percent* | |
| 1 | 40 | 31.2 | 0.05 | 0.01 | 0.01 | 0.52 | 0.28 | 0.13 | 21.9 | 27.5 | – |
| 7 | 41 | 14.2 | .07 | .03 | .03 | .79 | .69 | .98 | 1.4 | 7.4 | – |
| 10 | 41 | 6.6 | .17 | .06 | .04 | 1.69 | 1.32 | .90 | 4.9 | 11.7 | 34. |
| | | | | | | | | Average | 9.1 | 15.6 | 34.0 |
| DDT: | | | | | | | | | | | |
| 2 | 42 | 32.0 | 0.12 | .00 | .00 | 1.28 | .00 | .00 | 15.13 | 15.75 | – |
| 5 | 41 | 14.2 | .27 | .00 | .00 | 2.62 | .00 | .02 | 1.39 | 7.45 | – |
| 8 | 40 | 27.5 | .13 | .00 | .00 | 1.19 | .00 | .00 | 3.33 | 5.16 | 9.55 |
| | | | | | | | | Average | 6.62 | 9.13 | [1]9.55 |
| Carbaryl: | | | | | | | | | | | |
| 3 | 47 | 41.2 | 0.15 | .02 | .01 | 1.60 | .38 | .14 | 15.26 | 20.23 | – |
| 6 | 39 | 31.9 | .12 | .06 | .03 | 1.35 | 1.53 | .69 | .43 | 9.80 | – |
| 11 | 52 | 6.1 | .11 | .04 | .02 | 1.46 | .87 | .40 | 11.02 | 21.38 | 21.35 |
| | | | | | | | | Average | 8.24 | 17.14 | 21.35 |
| Trichlorfon: | | | | | | | | | | | |
| 12 | 26 | 27.6 | 0.02 | .01 | .00 | .25 | .09 | .03 | 9.52 | 10.49 | – |
| 4 | 36 | 4.9 | .04 | .00 | .01 | .49 | .07 | .12 | 1.28 | 3.85 | – |
| 9 | 37 | 20.2 | .05 | .01 | .00 | .51 | .20 | .02 | 2.22 | 6.51 | 12.15 |
| | | | | | | | | Average | 4.34 | 6.94 | [1]12.15 |

[1] Significantly different from check plots at the 99 percent level of confidence.

more foliage (99 percent level of confidence) than did carbaryl.

Effectiveness of suppression measures was judged by estimating DFTM population density in two ways: (a) computing the number of larvae pretreatment and posttreatment per 1000 sq. inches of foliage; and (b) computing the number of larvae per 100 shoots. Control was expressed as the percent reduction in population densities from the prespray levels. DFTM population densities are usually expressed on the basis of foliage or branch surface area. However, population densities based on 100 shoots should have closer correspondence to foliage damage in the new leaves than population densities based on 1000 sq. inches of branch or total foliar surface.

DDT treatments reduced population densities 4 days after application to an apparent zero within the limitations of our sampling effort. However, we detected no significant difference between the percent control obtained for carbaryl and trichlorfon and the checks. At 14 days, substantial reductions in population densities (DFTM/1000 sq. inches) had occurred in the plots treated with carbaryl and trichlorfon. Both chemicals had significantly reduced populations (95 percent level of confidence) when compared to those in the check plots. Neither, however, was as effective as DDT. Although the data suggest that trichlorfon was superior to carbaryl, the difference is not statistically significant. Analyses of larval populations per 100 shoots showed a significant difference for DDT only, for both the 4-day and 14-day data.

Table 2—*Incidence of virus in larval collections made during each sampling period at the study plots by treatment and plot, Halfway, Oregon, 1974* [1]

| Treatment and plot | Prespray | | | 1st Postspray (4 days) | | | 2nd Postspray (14 days) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Larvae collected | Larvae with virus 14 days | Larvae with virus 21 days | Larvae collected | Larvae with virus 14 days | Larvae with virus 21 days | Larvae collected | Larvae with virus 14 days | Larvae with virus 21 days |
| Check | | —*Percent*— | | | —*Percent*— | | | —*Percent*— | |
| 1 | 20 | 55 | 55 | 18 | 16.7 | 16.7 | 7 | – | 0.2 (Para- |
| 7 | 28 | 42.9 | 42.9 | 41 | 2.4 | 2.4 | 43 | – | 16.3 sitized) |
| 10 | 62 | 37.1 | 37.1 | 67 | 9.0 | 10.4 | 39 | – | 35.9 |
| Average | 36.67 (22.3) | 45.0 ( 9.13) | 45.0 ( 9.13) | 42.0 (24.5) | 9.37 ( 7.16) | 9.83 ( 7.17) | 29.67 (19.73) | – | 17.4 (17.9) |
| DDT | | | | | | | | | |
| 2 | 55 | 40 | 43.6 | – | – | – | – | – | – |
| 5 | – | – | – | – | – | – | 1 | – | 100.0 |
| 8 | 68 | 33.8 | 33.8 | – | – | – | – | – | – |
| Average | 61.5 ( 9.19) | 36.9 ( 4.38) | 38.7 ( 6.93) | | | | | | |
| Carbaryl | | | | | | | | | |
| 3 | 56 | 51.8 | 51.8 | 21 | 23.8 | 23.8 | 8 | – | 37.5 |
| 6 | 44 | 45.5 | 45.5 | 73 | 47.9 | 47.9 | 46 | – | 39.1 |
| 11 | 49 | 16.3 | 16.3 | 54 | 29.6 | 33.3 | 19 | – | 21.1 |
| Average | 49.67 ( 6.03) | 37.87 (18.94) | 37.87 (18.94) | 49.33 (26.31) | [2]33.77 (12.58) | [2]35.0 (12.14) | 24.33 (19.55) | | [2]32.57 ( 9.96) |
| Trichlorfon | | | | | | | | | |
| 12 | 10 | 50.0 | 50.0 | 5 | 20.0 | 20.0 | 2 | – | 0 |
| 4 | 15 | 40.0 | 40.0 | 5 | 40.0 | 40.0 | 4 | – | 50.0 |
| 9 | 30 | 26.7 | 26.7 | 15 | 26.7 | 26.7 | 2 | – | 0 |
| Average | 18.33 (10.41) | 38.90 (11.69) | 38.9 (11.69) | 8.33 ( 5.77) | [2]28.9 (10.18) | [2]28.90 (10.18) | 2.67 ( 1.15) | | 16.67 (28.87) |

[1] Values in parentheses are standard deviations.
[2] Significantly different from the check plots at the 99.9 percent level.

The effectiveness of each treatment was influenced by the coverage of the insecticides on the treatment or target area. Coverage depends upon spray distribution, the volume applied, the droplet sizes, and droplet density (*table 3*). The DDT treatment provided the best coverage of the target areas, averaging 0.121 gallons per acre (GPA) and 11.6 droplets per square centimeter on the spray plates and cards. Trichlorfon showed the next best coverage, averaging 0.115 GPA and 4.2 droplets/cm.[2] Carbaryl had the poorest coverage, averaging only 0.032 GPA and 1.6 droplets/cm.[2] The same nozzle size and spray pressure were used in all treatments; however, differences in viscosity produced different droplet sizes. Droplet size was smallest for DDT and largest for carbaryl. The average VMD's[13] were 132 for DDT, 287 for trichlorfon, and 314 for carbaryl.

## DISCUSSION

Because the three insecticides showed similar contact toxicities to DFTM in the laboratory, part of the superior field performance of DDT 4 days after spraying may be due to the better coverage obtained on the study plots. Coverage depends on volume of insecticide formulation applied and size and number of spray droplets per unit area. With all three insecticide treatments approximately the same amount of active material reached the ground: 12 percent for carbaryl and DDT, and 17 percent for trichlorfon. The performance of carbaryl was adversely affected, however, by poor coverage of the target area due to low volume of chemical applied, large-sized droplets resulting in low density of droplets on the spray plots, and poor spray distribution due to spray application under conditions of up-slope winds exceeding 7 mi/h.

DFTM larval mortality from virus infections was substantial in many of the plots during the prespray and postspray sample periods (*table 2*). This virus disease obscured the biological effects of the insecticides on the DFTM populations since it was impossible to distinguish virus-induced mortality from insecticide-induced mortality in the 4- and 14-day postspray samples showing reductions in larval populations on the treated plots. However, the carbaryl and trichlorfon treatments affected the incidence of virus among the surviving DFTM populations.

Table 3—*Spray application, deposit, and Douglas-fir tussock moth mortality, by treatment and plot, Halfway, Oregon, 1974*

| Treatment and plot | Application | | Spray deposit | | | | Mortality[1,2] | |
|---|---|---|---|---|---|---|---|---|
| | Dosage | Volume | Volume | | Drops | VMD | 4 days | 14 days |
| | *lb* | *gal /acre* | *gal /acre* | *Percent* | *cm²* | *μ* | *—Percent—* | |
| DDT: | | | | | | | | |
| 2 | 0.75 | 1.0 | 0.150 | 15.0 | 13.1 | 142 | 100.0 | 100.0 |
| 5 | .75 | 1.0 | .074 | 7.4 | 9.1 | 123 | 100.0 | 100.0 |
| 8 | .75 | 1.0 | .140 | 14.0 | 12.6 | 133 | 100.0 | 100.0 |
| Average | | | .121 | 12.1 | 11.6 | 132.7 | 100.0 | 100.0 |
| Trichlorfon: | | | | | | | | |
| 12 | 1.0 | .66 | 0.064 | 9.7 | 2.4 | 265 | 50.0 | 100.0 |
| 4 | 1.0 | .66 | .176 | 26.2 | 6.0 | 277 | 100.0 | 75.0 |
| 9 | 1.0 | .66 | .104 | 15.7 | 4.1 | 319 | 80.0 | 100.0 |
| Average | | | .115 | 17.2 | 4.17 | 287 | 76.7 | 91.7 |
| Carbaryl: | | | | | | | | |
| 3 | 1.0 | .66 | .020 | 8.0 | 1.2 | 221 | 86.7 | 93.3 |
| 6 | 1.0 | .66 | .036 | 14.4 | 2.2 | 360 | 50.0 | 75.0 |
| 11 | 1.0 | .66 | .041 | 16.4 | 1.3 | 363 | 63.6 | 81.8 |
| Average | | | .032 | 12.9 | 1.57 | 314 | 66.8 | 83.4 |

[1] Based on number of DFTM/1000 sq. inches of foliage.

[2] The DFTM mortalities on the check plots averaged 67.3 and 71.2 percents for the 4- and 14-day postspray sampling periods respectively. These were significantly different from the mortalities of DFTM on the carbaryl and trichlorfon plots at the 95 percent level of confidence.

Although the average percent of larvae infected with virus was similar among the study plots in the prespray samples, the prevalence rate of polyhedrosis in DFTM from the 4-day postspray samples of the carbaryl and trichlorfon treated plots averaged significantly higher (99.9 percent level) than sample from the untreated check areas and this difference continued through the 14-day postspray samples in the carbaryl-treated plot (*table 2*). This suggests an interaction between the insecticide treatments and the virus. Larvae infected with virus survived the insecticide treatments better than healthy larvae. The prevalence of polyhedrosis appeared to surge and ebb through the untreated DFTM populations over time. The percent of DFTM larvae infected with virus in the check plots was significantly lower (99.9 percent level) in the 4-day postspray samples than in the prespray samples, but it had begun to increase by the 14-day sample period. In contrast, it remained relatively constant in the insecticide-treated populations through all the sampling periods. In a survey in mid-October, we found no egg masses on any of the study plots or nearby unsprayed areas.

## CONCLUSIONS

The confounding influence of variable DFTM population densities and high prevalence rates of polyhedrosis make it difficult to draw definitive conclusions. The comparative efficacy of the three insecticides cannot be judged solely on the basis of their performance in population suppression owing to the effect of the virus disease under the conditions of this study; however, it appears that . . .

1. The DDT treatment was the most effective in reducing DFTM populations and preserving tree foliage. While less effective in reducing DFTM populations, trichlorfon was not significantly different from DDT in preserving foliage.

2. Virus played a major but unmeasured role in the reduction of tussock moth populations at the 4-day and 14-day postspray dates and on the eventual collapse of the populations throughout the study areas. We were unable to evaluate what appeared to be an interaction between the virus and the insecticides on DFTM populations. Virus-infected larvae survived the insecticide treatments better than healthy larvae. No new egg masses were found in any of the study areas the following autumn.

3. The test design in which spray volume and droplet size differed among the three insecticides similar in their toxicities to DFTM may not have provided any valid comparison of efficacy between these materials. DDT, for example, may have shown superior results partly because of better foliage coverage. All materials should have been applied at equal dosage rates and volumes and within a similar droplet-size spectrum.

4. Variation in droplet size, however, did suggest a relationship between VMD and insecticide efficacy with smallest droplets giving the best spray coverage and densities.

## NOTES

[1] Mounts, Jack, David McComb, Stanley W. Meso, LeRoy F. Kline, and Galen C. Trostle. 1973. *Cooperative tests of chemical insecticides for control of the Douglas-fir tussock moth.* Pacific Northwest Region, Forest Serv., U.S. Dep. Agric., Corvallis, Oreg. 41 p.

[2] Williams, Carroll B., Jr. 1973. *Field tests of four insecticides against the Douglas-fir tussock moth in Oregon.* Perm. Assoc. Comm. Proc., West. For. and Conserv. Assoc., Portland, Oreg. 1973:77-83.

[3] This publication reports research involving pesticides. It does not contain recommendations for their use, nor does it imply that the uses discussed here have been registered. All uses of pesticides must be registered by appropriate State and/or Federal agencies before they can be recommended.

[4] Criteria set in accordance with advice of Dr. Clarence G. Thompson, Pacific Northwest Forest and Range Exp. Stn., Corvallis, Oreg.

[5] Laboratory data by Jacqueline L. Robertson, Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

[6] Perkins, Randall F., and Robert E. Dolph, Jr. 1967. *Operational and entomological report, 1965 Burns Project-Douglas-fir tussock moth control.* Pacific Northwest Region, Forest Serv., U.S. Dep. Agric., 28 p., illus.

[7] Unpublished data by Carroll Williams and Patrick Shea, Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

[8] Maksymiuk, Bohdan. 1975. *Marking methods for improving aerial application of forest pesticides.* USDA Forest Service Res. Note PNW-262, 10 p., illus. Pacific Northwest Forest and Range Exp. Stn., Portland, Oreg.

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[11] Maksymiuk, B., J. Neisess, R. A. Waite, and R. D. Orchards. 1975. *Distribution of aerially applied mexacarbate in a coniferous forest and correlation with mortality of Choristoneura occidentalis (Lepidoptera:Tortricidae).* Z. Ang. Ent. 70:194-204.

[12] Volume median diameter (VMD) is the theoretical center of the spray droplet size spectrum, i.e., half of the spray mass is in droplets larger than the VMD and half in droplets smaller than the VMD.

[13] Maksymiuk, Bohdan. 1964. *The drop size spectra method for estimating the mass median diameter of aerial sprays.* U.S. Forest Serv. Res. Paper WO-1, 11 p., illus. Forest Serv., U.S. Dep. Agric., Washington, D.C.

## The Authors

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